International Journal of Innovative Research in Science and Engineering
Vol. No.2, Issue 09, September 2016
www.ijirse.com
ISSN (O) 2454-9665
ISSN (P) 2454-0663

EXPERIMENTAL INVESTIGATION ON THE DRILLING PARAMETERS AFFECTED BY NANOFLUID USING MINIMUM QUANTITY LUBRICATION

Ivan Sunit Rout

Department of Mechanical Engineering, Christ University Faculty of Engineering, Bangalore, India

ABSTRACT

Numerous nano particles in oil additives as lubricants and coolants have been used in diverse applications such as automobiles and electric devices due to their superior characteristics in terms of lubrication, wear resistance and cooling. Therefore, those nano particles could also be applied to various machining processes with minimum quantity lubrication (MQL) approach for surface quality enhancement, tool life extension and environmental friendliness. Al_2O_3 has been selected for nano particles in this study due to its non-toxicity to humans and spherical shapes for enhanced tribological attributes. In machining applications, other properties of the selected nano particle such as hardness and thermal conductivity are also significant for affecting lubrication and wear behaviors.Thrust Force has been determined with minimum quantity lubrication effect using two base fluids.

Keywords- Thrust Force, Nanofluid, Paraffin oil, Engine oil

I. INTRODUCTION

MWFs are commonly used to cool and lubricate the contact interfaces of a tool and workpiece. The application of a MWF improves the surface quality of the workpiece, prolongs tool life, and removes chips from the cutting zone. Despite this excellent performance, MWFs can have adverse effects on human health and the environment. Calvert et al. reported that exposure to MWF can increase the risk of cancer of the larynx, rectum, pancreas, skin, scrotum, and bladder. Another important issue to be resolved is the disposal cost of used MWF. According to Klocke and Eisenblatter and Braga et al., the cost of disposing of waste oil accounted for a high percentage of total manufacturing cost to reduce environmental loads.

For reducing MWF usage dry machining techniques and those using compressed cold air and MQL have mainly been studied and are categorized as environmental friendly machining process. MQL machining uses mixture of high pressure air and tiny amount of oil, which is supplied to the machining interface. For MQL machining, the fluid vapourises during the process leaving dry chips, thus it is cost effective and environmental friendly.

ISSN (O) 2454-9665
ISSN (P) 2454-0663

Hafenbradle and malkin studied a grinding process using MQL and found that it reduced the amount of grinding power and grinding wheel wear more than conventional flood lubrication. Hwang et al. conducted parametric study and optimization of end-milling processes using taguchi method under the conditions of MQL lubrication. They found the optimal machining conditions for minimize the cutting force and surface roughness.

1.1 CNC Vertical Milling Machine

Milling is the machining process of using rotary cutters to remove materialfrom a workpiece advancing (or feeding) in a direction at an angle with the axis of the tool. It covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes in industry and machine shops today for machining parts to precise sizes and shapes.

Milling can be done with a wide range ofmachine tools. The original class of machine tools for milling was the milling machine (often called a mill). After the advent of computer numerical control (CNC), milling machines evolved into machining centers (milling machines with automatic tool changers, tool magazines or carousels, CNC control, coolant systems, and enclosures), generally classified as vertical machining centers (VMCs) and horizontal machining centers (HMCs). The integration of milling into turning environments and of turning into milling environments, begun with live tooling for lathes and the occasional use of mills for turning operations, led to a new class of machine tools, multitasking machines (MTMs), which are purpose-built to provide for a default machining strategy of using any combination of milling and turning within the same work envelope.

1.2 Workpiece

The ductility, hardness and tensile strength is a function of the amount of carbon and other hardening agents present in the alloy. Mild steel is a steel in which the main interstitial alloying constituent is carbon in the range of 0.12- 2.0%. Mild steel is also known as plaincarbon steel is now the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications.

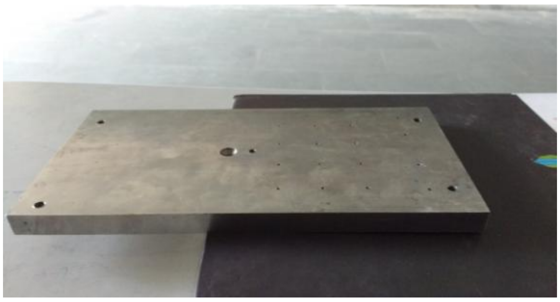


Fig 1 Mild Steel workpiece

1.3 Base Fluid

To increase heat transfer and tribological properties of nanofluid basefluid is used. Tribology research shows that lubricating oils or basefluids with nano particles additives exhibits improve load carrying capacity, anti-wear and friction reduction properties. In this experiment we will use paraffin oil, engine oil, as all these are eco-friendly, low cost and effective as a basefluids. Paraffin oil offers properties such as good lubricity, smoothness and softness and resistance to moisture in the formulations. Engine oil has high viscosity and density.It significantlyimproves the anti-wear properties, if it is used as base fluid.

Fig 2 Paraffin Oil

Fig 3 Engine Oil

1.4 Characterisation and Selection of Nanoparticles

The structure, shape, and size of nano particles play an important role in their tribological properties. Choi et al. and Lee et al. studied the lubrication characteristics of nanofluids with nano particles having various shapes and sizes. They found smaller particle additives decrease the workpiece wear and the friction coefficient. Micro-scale particles can degrade the lubrication characteristics of pure oil because they are dispersed in an unstable condition. They also found that spheres have a better lubrication effect than fiber shapes because of their stable dispersion. Battez et al. investigated the anti-wear behavior of nano particle suspensions in a polyalphaolefin6 and found that the size and hardness of nano particles in an oil additive can be important to the tribological properties.

Jeng et al. reported toxicity profiles of numerous metal oxide nano particles, including TiO_2, ZnO, Fe_3O_4, Al_2O_3, and CrO_3, with particle sizes ranging from 30 to 45 nm. They summarized that ZnO was highly toxic, whereas Al_2O_3, Fe_3O_4 and TiO_2 exhibited moderate or slight toxicity at the high concentrations. CrO_3 displayed no toxicity at the tested concentrations.

Therefore, Al_2O_3 has been selected for nano particles in this study due to its non-toxicity to humans and spherical shapes for enhanced tribological attributes. In machining applications, other properties of the selected nano particle such as hardness and thermal conductivity are also significant for affecting lubrication and wear behaviors. Table 1 shows the hardness and thermal conductivity of Al_2O_3 nano particles. It also has phase

International Journal of Innovative Research in Science and Engineering
Vol. No.2, Issue 09, September 2016
www.ijirse.com
ISSN (O) 2454-9665
ISSN (P) 2454-0663

stability and good dimensional stability when dispersed in water. It can significantly improve density, smoothness, thermal fatigue resistance, fracture toughness, creep resistance and polymer products wear resistance. It provides good thermal insulation.

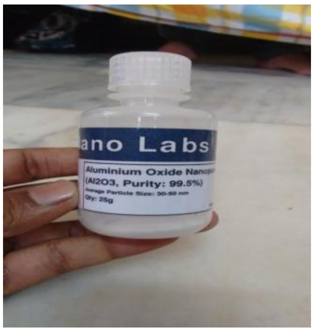


Fig 4 Aluminium Oxide Nanoparticles

Table 1 Specification of Nanoparticles

Molecular formula	Al_2O_3
Morphology	Spherical
Hardness	1700-2000
Thermal conductivity	30 w/m-k
Particle size	30-50 nm
Atomic weight	101.96 g mol^{-1}
Melting point	2055^{o} c

1.5 Response Surface Methodology

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. A response or the output variable is the outcome of certain vital factors or we can say the response is influenced by change of these vital factors. Basically a response surface design is used to map theresponse surface.Essentially, we are finding a model that describes the relationship between the vital factors and the response. Basically we have three reasons why we want to map aresponse surface. They are :-

- To find the factor settings that optimize the response (max./min. problem, or hitting a specific target)
- In order to improve a process, you'll need to understand how certain factors influence the response.
- Find out what tradeoffs can be made in factor settings, while staying near the optimal response.

By design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response.

The objective of DOE is the selection of the points where the responseshould be evaluated.Most of the criteria for optimal design of experiments are associated with the mathematical model of the process. Generally, these mathematical models arepolynomials with an unknown structure, so the corresponding experiments aredesigned only for every particular problem.The choice of the design of experimentscan have a large influence on the accuracy of the approximation and the cost ofconstructing the response surface.

A DOE approach will be introduced to find critical variables havingsignificant effects on the micro-drilling performances. In the DOE approach, central composite design (CCD) will applied for the design of micro-drilling experiments. In this research, fourcontrollable process factors i.e.drill diameter, feed rate, spindle speed and volumetric concentration of nano-diamond particles will be taken into considerations, and thus 16 experimental runs will sorted for each base fluid

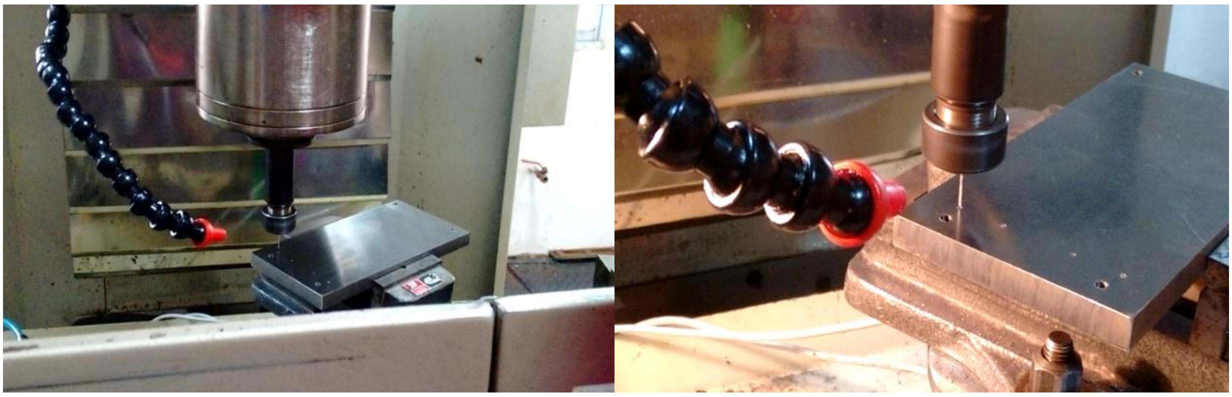
In addition, responses considered in the experiments will be drilling torque, drilling thrust force and material removal rate (MRR).

II. EXPERIMENTAL SET-UP

In this experiments a DOE (Design Of Experiment) approach is used to find critical variables having significant effects on the drilling performances. In the DOE approach, central composite design (CCD) was applied for the design of drilling experiments. Here four controllable process factors - drill diameter, feed rate, spindle speed and volumetric concentration of nano-aluminium oxide particles and one axial point are taken into considerations, and thus 16 experimental runs are sorted for each base fluid - paraffin oil, ethylene glycol. Responses which will be considered in the experiments are drilling torque, drilling thrust force and material removal rate (MRR). The process factors and levels are selected by considering our previous research (Nam et al., 2011). Table 1 shows the process factors and their levels for the experiments. There are two levels of each process factor are considered.

A numberof drilling experiments will be conducted in the miniaturized desktop machine tool system. The 3-degrees-of-freedom (DOF) miniaturized desktop machine tool system is developed based on the horizontal configuration. It has linear slides for a precision positioning system and the electric spindle having the maximum spindle speed of 8,000 RPM for a rotating system. In addition, the load/torque cell is assembled to the linear slide with 2 mm lead, and then the tool steelworkpiece is attached to the load/torque cell to measure thrust forces and torques. The overall size of the developed miniaturized desktop machine tool system is 280 mm 360 mm 290 mm. Themicro-drill used in the experiments is an coated carbide twist drill, and the maximum drilling depthwill be 0.4 mm. In this experiment we are going to take 5mm thicker sheet of tool steel as a work-piece, having length of 80 mm and breadth of 50 mm. The micro drill-bit which is applied in this experiment is coated carbide drill-bit which is a type of twisted drill & maximum drill depth is 0.4mm.The standard diameter of this type of drill-bit is0. 1mm. The point angle and flute length are 118° and 23 mm respectively. The output parameter of torque and thrust force can be measured by the arrangement of 9272A type Kistler Co. prepared quartz 4 component dynamometer and 5070A type multi-channeled charge amplifier.

International Journal of Innovative Research in Science and Engineering
Vol. No.2, Issue 09, September 2016
www.ijirse.com
ISSN (O) 2454-9665
ISSN (P) 2454-0663



(a) (b)

Fig 5 (a) Workpiece mounted on CNC Vertical Milling Machine (b) Drilling operation running

III. METHODOLOGY

A DOE approach will be introduced to find critical variables havingsignificant effects on the micro-drilling performances. In the DOE approach, central composite design (CCD) will applied for the design of micro-drilling experiments. In this research, fourcontrollable process factors i.e.drill diameter, feed rate, spindle speed and volumetric concentration of nano-diamond particles will be taken into considerations, and thus 16 experimental runs will sorted for each base fluid

In addition, responses considered in the experiments will be drilling torque, drilling thrust force and material removal rate (MRR).

Table 2 shows the process factors and their levels for the experiments. As can be seen in Table 2, two levels of each process factor will be considered.

Input variable-drill diameter, feed rate,spindle speed,volume concentration

Response-drill torque, thrust force, MRR

Level- high grade level (1) low grade level(-1)

Run-2^3=8

Table 2 Process factors and levels in DOE

Level	Drill diameter (mm)	Feed rate (mm/min)	Spindle speed (rpm)	Nanofluid Concentration (% vol.)
1	1	0.04	3000	4
-1	1	0.05	5000	2

ISSN (O) 2454-9665
ISSN (P) 2454-0663

Table 3 Without nanofluid

Run	Drill dia. (mm)	Feed rate (mm/min)	Spindle speed (rpm)	Vol. Conc. (% vol.)	Response	
					Thrust Force (Kg-f)	MRR
1	1	0.04	3000	0	2.1	0.0314
2	1	0.04	3000	0	2.3	0.0314
3	1	0.05	5000	0	2.4	0.0392
4	1	0.05	5000	0	2.6	0.0392

3.1 Regression models for drilling torques and thrust forces

The regression models of response variables in terms of process Factors - drill diameter, feed rate, spindle speed, nanofluid volumetric concentration will be obtained by using the commercial statistics package MINITAB. The second-order regression functions of drilling torques and thrust forces in the cases of base fluid of paraffin oil and engine oil will be formulated, respectively. The type of the models will be full quadratic , and their validity will be evaluated by ANOVA and coefficients of determination (R^2).The regression functions of the drilling torques and thrust forces in the case of the base fluid of paraffin oil and engine oil are to be calculated. Here the equation given below is the torque equation when paraffin oil is used as base fluid. It is mentioned to give a rough sketch about the equation that will be determined ahead during the time of experiment taking engine oil and paraffin oil as base fluid.

Table 4 Experimental design of pure nanofluid MQL drilling processes with base fluid paraffin oil

Run	Drill dia. (mm)	Feed rate (mm/min)	Spindle speed (rpm)	Vol. Conc. (% vol.)	Response	
					Thrust Force (Kg-f)	MRR
1	1	0.04	3000	2	1.5	0.0314
2	1	0.04	3000	4	1.7	0.0314
3	1	0.04	5000	2	1.4	0.0314
4	1	0.04	5000	4	1.5	0.0314
5	1	0.05	3000	2	1.7	0.0392
6	1	0.05	3000	4	1.8	0.0392
7	1	0.05	5000	2	1.6	0.0392
8	1	0.05	5000	4	1.8	0.0392

ISSN (O) 2454-9665
ISSN (P) 2454-0663

Table 5 ANOVA table for thrust force (paraffin oil)

Term	coefficent	SE coefficient	t	P
Constant	1.56875	0.03883	40.400	0.001
f	0.19875	0.03883	5.118	0.036
s	-0.05375	0.03883	-1.384	0.301
n	0.08625	0.03883	2.221	0.156
f×s	0.13625	0.03883	3.509	0.072
f×n	-0.00875	0.03883	-0.225	0.843

S=0.04082 R^2=95.8% Adj.R^2=85.2%

Regression function for parafin oil are:-

$f_{th-p}(d,f,s,n) = 4.4050 - 64.0000f - 0.0013s + 0.1650n + 0.0272f\times s - 1.7500f\times n$

Table 6 Experimental design of pure nanofluid MQL drilling processes with base fluid Engine Oil

Run	Drill dia. (mm)	Feed rate (mm/min)	Spindle speed (rpm)	Vol. Conc. (% vol.)	Response	
					Thrust Force (Kg-f)	MRR
1	1	0.04	3000	2	1.7	0.0314
2	1	0.04	3000	4	1.8	0.0314
3	1	0.04	5000	2	1.6	0.0314
4	1	0.04	5000	4	1.6	0.0314
5	1	0.05	3500	2	1.5	0.0392
6	1	0.05	3500	4	1.2	0.0392
7	1	0.05	5000	2	1.1	0.0392
8	1	0.05	5000	4	1.2	0.0392

Table 7 Anova table for thrust force (engine oil)

Term	coefficent	SE coefficient	t	P
Constant	1.50250	0.03824	39.289	0.001
f	-0.20750	0.03824	-5.426	0.032
s	-0.08000	0.03824	-2.092	0.172
n	-0.00250	0.03824	-0.065	0.954
f×s	-0.02500	0.03824	-0.654	0.580
f×n	-0.03250	0.03824	-0.850	0.485

S=0.1082 R^2=94.6% Adj.R^2=81.1%

ISSN (O) 2454-9665
ISSN (P) 2454-0663

The regression functions for engine oil are:-

$f_{th-e}(d,f,s,n) = 1.9200 – 2.0000f + 0.0001s + 0.2900n – 0.0050f×s – 6.5000f×n$

3.2 NANOFLUID SYNTHESIS

Al_2O_3 is not stable in paraffin oil; therefore, surfactants are used for dispersion of the Al_2O_3 nanoparticles. The surfactant is prepared by mixing surface active agents (TW80 and SP80) with the ratio of 1: 1 in volume, and then the surfactant, DI water and Al_2O_3 are mixed in a ratio of 8:5:2, by volume. The volume fraction of the Al_2O_3 powder is calculated from the weight of the dry powder using the true density provided by the supplier and the total volume of the suspension. The mixtures are then de-agglomerated by intensive ultrasonication for 3 hours after mixing with the base fluid – paraffin oil. Finally, the suspension is homogenized for 1 hour by magnetic force agitation. Dispersion of the Al_2O_3 nanoparticles is monitored for 24 hours without any trace of visible particle sedimentation.

In this study an optimal composition of 0.5 volume % Al_2O_3nano-particle separately dispersed in SAE 15W40 diesel engine oil by sonication technique. Samples can be stabilized using a surfactant oleic acid to prevent sedimentation of nano particles. The oil properties can be studied by measuring the viscosity index (VI), total acid number (TAN) and flash point temperature. The stability of nano-particles in oil can be observed by measuring the absorption value over time using ultraviolet spectrometer. The dispersion of nano-oil can be stable upto 168 hour before the sedimentation occurs (M.I. Hakami Chua Abdullah et al. 2014. Effect of HBN (Al_2O_3 nano particles on engine oil properties).

Fig 6 Preparation of nanofluid using magnetic stirrer

International Journal of Innovative Research in Science and Engineering
Vol. No.2, Issue 09, September 2016
www.ijirse.com
ISSN (O) 2454-9665
ISSN (P) 2454-0663

IV. RESULTS

4.1 Contour plots of Thrust Forces in case of Engine oil

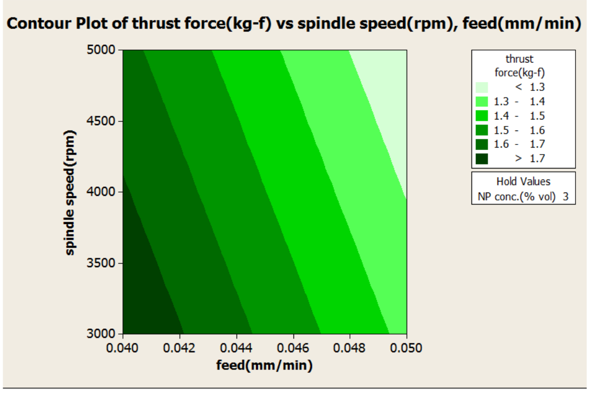


Fig 7 Feed rate vs spindle speed

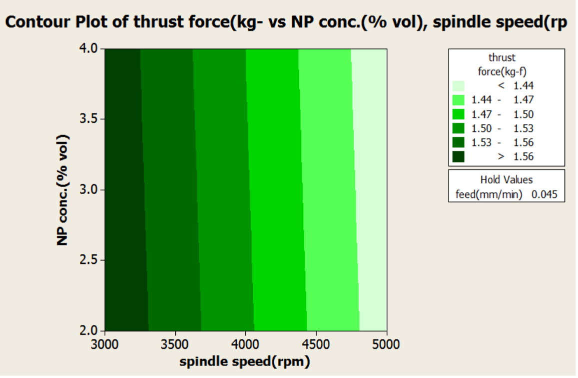


Fig 8 Spindle speed vs volume concentration

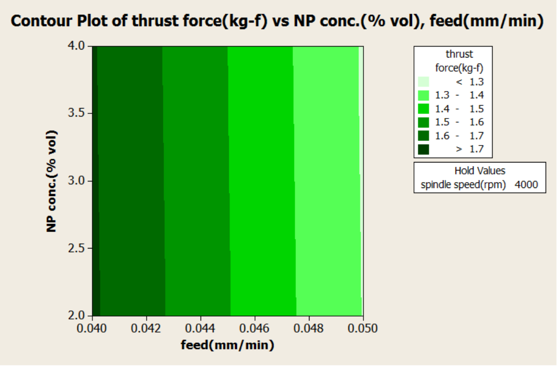


Fig 9 Feed rate vs volume concentration

4.2 Contour plots of Thrust Forces in case of Paraffin oil.

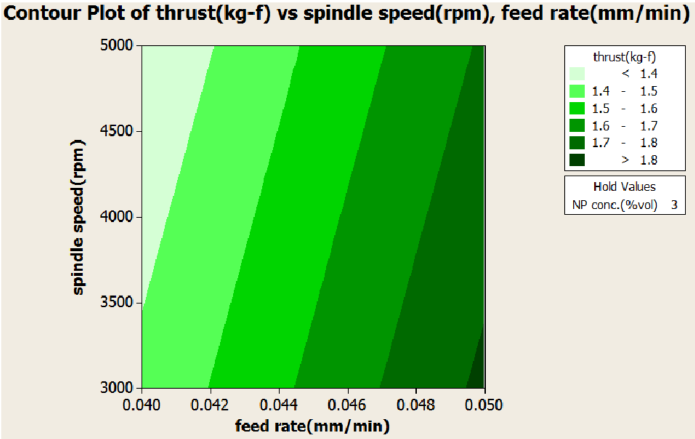


Fig 10 Feed rate vs spindle speed

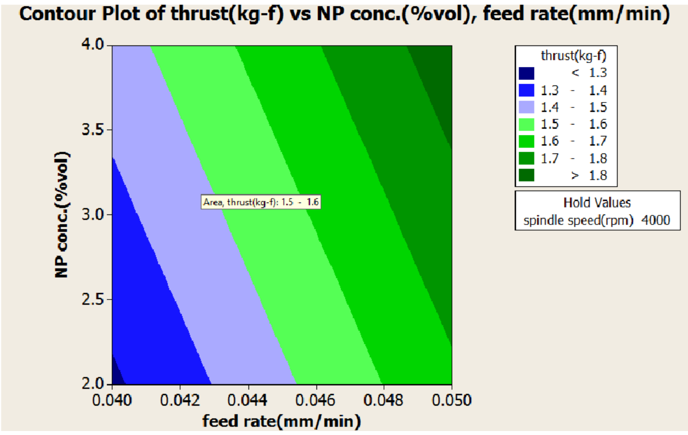


Fig 11 Feed rate vs volume concentration

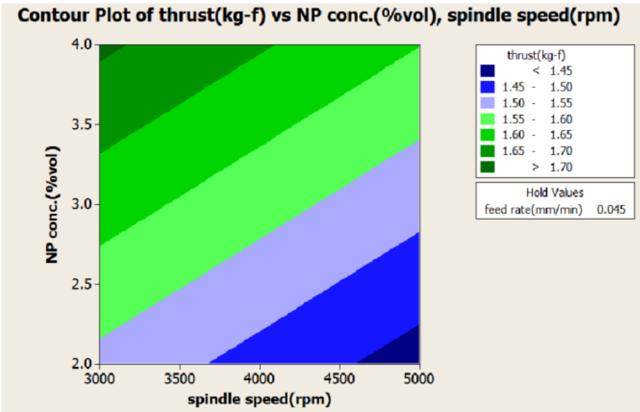


Fig 12 Spindle speed vs volume concentration

ISSN (O) 2454-9665
ISSN (P) 2454-0663

V. CONCLUSION

In this research, the optimization of nano fluid MQL drilling process using nano Al_2O_3 and base fluids of paraffin oil and engine oil was conducted based on RSM. In order to formulate the regression functions of drilling torques and thrust forces, total 8 experiments were designed and conducted in each case of base fluid of paraffin oil and engine oil, respectively. In the experiments, four process factors drill diameter, feed rate, spindle speed and nano fluid volumetric concentration were considered, and the measured and calculated response variables were drilling thrust forces and MRRs.

The formulated regression functions were validated by ANOVA with high coefficients of determination (R^2) which were more than 94%. From the ANOVA analysis, it was overall found that feed rate was more dominant than spindle speed and volumetric concentration to have influence on drilling torques and thrust forces in both cases of base fluids of paraffin oil and engine oil. In addition, the self-interaction of nanofluid concentration was statistically significant for influencing drilling torques and thrust forces for both cases. The 2D contour plots of thrust forces were then created, and the influences of each process factor on the drilling performances were investigated. It was found that the minimum drilling torques and thrust forces were occurred at high spindle speed (5,000 RPM) and the nano fluid volumetric concentration in the vicinity of 2%.

The obtained optimal results of the nano fluid MQL drilling process factors were similar in both cases of basefluid of paraffin oil and engine oil except feed rate. At lower feed rate, high spindle speed and less volume concentration better results were found in case of paraffin oil. But engine oil gave better result at higher feed rate than paraffin oil. This difference could be attributed to different physical property of the base fluid such as viscosity. Since the paraffin oil had much higher viscosity, it might be necessary to agitate the nano particles with slower speed for them to be uniformly dispersed. Therefore, the low feed rate could be desired during the drilling process with the paraffin oil based nano fluid.

In order to validate the calculated optimal process factors, the micro-drilling experiments under the conditions with optimal process factors were conducted. The measured thrust forces and MRRs were similar to those calculated from the model within the margin of 5%, and the validity of the optimal values was verified.

To increase drilling productivity, process factors like feed rate, drill diameter, spindle speed and nano fluid concentration should be considered and to have significant influences on these process factors base fluids selection is very important.

REFERENCES

[1] Ramesh Kannan.C, Prathap.J, Padmanabhan.P, Experimental investigation of tool wear in turning of inconel 718 material, International Conference on Emerging Engineering Trends and Science (ICEET), 2016, 1-6.

[2] M.S. Najiha, M.M. Rahman, K. Kadirgama, M.M. Noor, and D. Ramasamy, Multi-objective optimization of minimum quantity lubrication in end milling of aluminum alloy AA6061T6, International Journal of Automotive and Mechanical Engineering, 12, 2015, 3003-3017.

ISSN (O) 2454-9665
ISSN (P) 2454-0663

[3] Y.Shokoohi,E.Shekarian, Application of Nanofluids in Machining Processes-A Review, Journal of Nanoscience and Technology, 2(1), 2016, 59–63.

[4] Mayur L. Jadhav, Prof.S.C. Borse, Effect of Nano fluid in High Speed Machining of Metals: A Review, International Journal for Scientific Research & Development, 4(4), 2016, 774-776.

[5] R. Saidur, K.Y. Leong, H.A. Mohammad, A review on application challenges of Nanofluid, Renewable and Sustainable Energy Reviews 15, 2011, 1646- 1668.

[6] Anuj Kumar Sharma, Arun Kumar Tiwari, Amit Rai Dixit, 2015, Mechanism of Nanoparticles functioning and Effects in Machining Processes: A Review", Materials Today: Proceedings 2, 3539 – 3544.

[7] D.Dudzinski, A.Devillez, A.Moufki, D.Larraouquere, V.Zerrouki, J. Vigneau, 2004, A Review of Developments towards dry and high speed machining of Inconel 718, International Journal of Machine Tools & Manufacture 44, 439-456.

[8] P Subhash Chandra Bose, C S P Rao,Kishore Jawale,2014, Role of MQL and nano fluids on the machining of nicrofer c263, 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014),December 12th–14th.